Maar sediment in central Vietnam Highland near Pleiku: An archive of regional monsoon intensity?

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Current global warming increases atmospheric humidity and will likely affect the East-Asian monsoon system across Vietnam. It is essential to understand the long-term regional climatic variability to properly evaluate present and potential future trends along global climate change. In the absence of a long written history and instrumental records in Vietnam, we must rely on geoarchives recording the paleoenvironmental history. Sediments from East-Asian maar lakes provide long-term records of monsoon variability, position and strength, for example in Cambodia, Myanmar and China (e.g., Sharma, 2014; Sun et al., 2016; Yang et al., 2016). Central Vietnam's Pleiku volcanic field features numerous maar lakes and dry maars which formed before 0.2 Ma ago (Nguyễn et al., 2013). Their natural sedimentary archives extend from the Holocene deep into the Pleistocene (Kitagawa et al., 2015; Nguyễn-Văn et al., 2017).

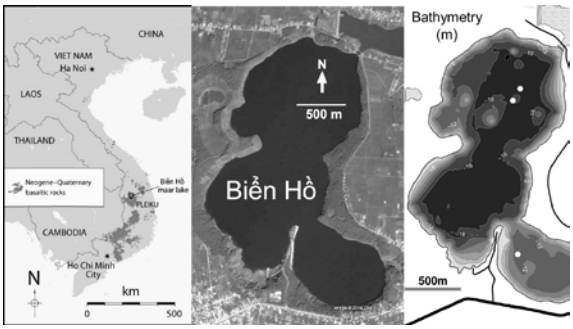

Fig. 1 – Central Vietnam's Highland features a cluster of maars near Pleiku. We cored the deepest and other parts of Biển Hồ maar lake (three white hexagons on bathymetric map) and some other maars in the area.

In three field campaigns between March 2016 and November 2017, we recovered numerous exploratory, up to 3.5 m deep gravity and piston cores from Biển Hồ maar lake near Pleiku (14° 03'03.5" N, 108° 00'00.2" E; Fig. 1) at water depths up to ~21 m (Fig. 2). A slightly cohesive microbial mat (Fig. 3B) has been observed to cover organic-rich, anoxic, sapropelic sediment below, except for occasional clay-rich flood layers following intense precipitation, such as in the fall of 2016 (United Nations, Viet Nam Office, 2016).

Fig. 2 – Gravity and piston coring in November 2017 on an improvised platform on Biển Hồ maar lake from water depths up to ~21 m.

The most recent ~15 cm of sediment are visibly laminated, whereas deeper sediment is typically dark-olive with rare color boundaries, yet XRF and magnetic susceptibility data suggest mm-scale variance over depth. Deeper sediment recovered in November 2017 contained horizontally positioned, well-preserved leaves and grass fragments that are subject to AMS radiocarbon dating (Fig. 3A).

A November 2017 hydrographic survey in Biển Hồ maar lake demonstrated thermal stratification and oxygen-depleted bottom water. By November 2017, iron (III)-containing reddish minerals in the topmost flood layer from 2016 (Fig. 3C) had been reduced to dark iron (II)-containing minerals and had been covered by a newly deposited bacterial mat on olive sediment.

Our preliminary observations suggest that Biển Hồ maar lake's suboxic bottom water protects modern laminated sediment from bioturbation (Fig. 4). Even if deeper, dark-olive sediment fails to be consistently laminated, careful documentation of its

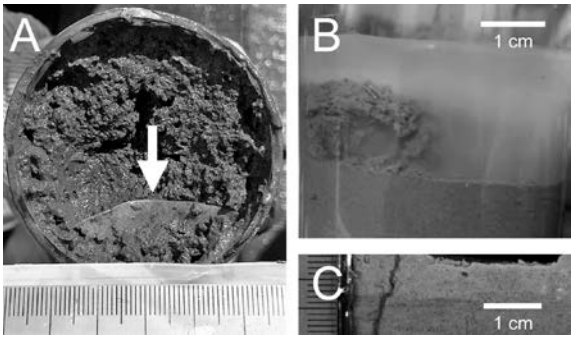

Fig. 3 – **A**: A well-preserved leaf was found in a core below the piston at a depth of 180 cm in Biển Hồ sediment. Other leaves, clusters of grass fragments, and wood bark were recovered in November 2017 from more than 12 horizons for radiocarbon dating. **B**: A curled-up microbial mat from the sediment/water interface after coring in March 2016. **C**: A reddish, freshly deposited 2016 flood layer was recovered in January 2017 above darker, olive sediment.

mineral content over depth may reveal a record of paleoflooding in terms of occasionally enhanced influx of weathering products from the maar's crater in response to potentially stronger monsoon activity or changes in landcover around the maar.

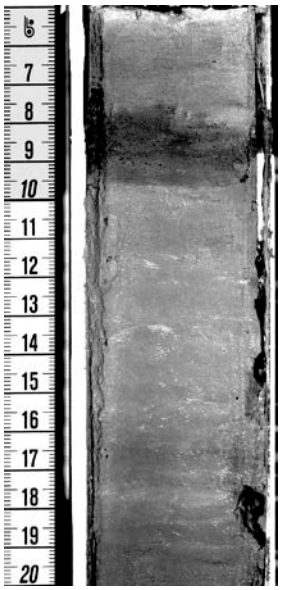

Fig. 4 – Photograph of a gravity core from Biển Hồ maar lake from March 2017 that was opened at LacCore in July 2017. Despite partial oxidation and disturbance at the top during transport from Pleiku to Hanoi, unrefrigerated storage in Hanoi, and transport to the USA, the core preserved evidence of lamination. The depth scale is in cm.

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References

Kitagawa, H., Dang, X.P., Hayashida, A., Nakamura, T., 2015. Variations in South Asian Monsoon over the last 13 kyr inferred from biogeochemical properties of maar sediment in the central highland of Vietnam. AGU Chapman Conference, Hong Kong SAR, China, 14-18 June, 2015. https://agu.confex.com/agu/monsoon/webprogram/Paper37349.html

Nguyễn, H., Flower, M.F.J., Cung, T.C., Phạm, T.X., Hoàng, V.Q., Trần, T.S., 2013. Collision-induced basalt eruptions at Pleiku and Buôn Mê Thuột, south-central Viet Nam. Journal of Geodynamics 69: 65-83. https://doi.org/10.1016/j.jog.2012.03.012

Nguyễn-Văn, H., Nguyễn-Thùy, D., Schimmelmann, J.P., Zolitschka, B., Tạ-Văn, T., Nguyễn-Ánh, N., Tạ Hòa, P., Đặng-Phương, T., Lê-Quyết, T., Nhi Phạm-Nữ, Q., Huỳnh-Kim, V., Schimmelmann, A., 2017. Exploring the paleoenvironmental potential of laminated maar sediment in central Vietnam: An archive of regional paleo-flooding? PAGES Zaragoza 2017 5th Open Science Meeting, 9-13 May, 2017, Zaragoza, Spain. http://eosvnu.net/wp-content/uploads/2016/10/Poster_Spain.jpg

Sharma, R.R., 2014. Precipitating Change. Holocene climatic change in the Asian monsoon based on sediment archives from tropical lakes. M.Sc. thesis, The University of Sydney, Australia, 170 p. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=10&ved=0ahUKEwiKp6n0gvrXAhVLGpQKHVuzBTsQFghVMAk&url=https%3A%2F%2Fses.library.usyd.edu.au%2Fbitstream%2F2123%2F12500%2F1%2F2015_Roshni_Sharma_thesis.pdf&usg=AOvVaw2KAcD_bpnLTPU8vrbCbqIO

Sun, Q., Shan, Y., Sein, K., Su, Y., Zhu, Q., Wang, L., Sun, J., Gu, Z., Chu, G., 2016. A 530 year long record of the Indian Summer Monsoon from carbonate varves in Maar Lake Twintaung, Myanmar. Journal of Geophysical Research: Atmospheres 121 (10): 5620-5630. https://dx.doi.org/10.1002/2015JD024435

United Nations, Viet Nam Office, 2016. Details for Viet Nam: Floods Central Viet Nam - Office of the Resident Coordinator Situation Report No. 1. http://un.org.vn/en/publications/doc_details/533-viet-nam-floods-central-viet-nam-office-of-theresident-coordinator-situation-report-no-1.html

Yang, Y., Zhang, H., Chang, F., Meng, H., Pan, A., Zheng, Z., Xiang, R., 2016. Vegetation and climate history inferred from a Qinghai Crater Lake pollen record from Tengchong, southwestern China. Palaeogeography, Palaeoclimatology, Palaeoecology 461: 1–11. https://doi.org/10.1016/j.palaeo.2016.07.017